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Risk Management for the Optimal Order Quantity by Risk-Averse Suppliers of Food Raw Materials

Tyrone T. Lin and Shu-Yen Hsu *

Department of International Business, National Dong Hwa University, No. 1, Sec. 2, Da Hsueh Rd., Shou-Feng, Hualien 97401, Taiwan; tjlin@gms.ndhu.edu.tw
* Correspondence: 810232010@gms.ndhu.edu.tw; Tel.: +886-3-890-3051

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Abstract: In uncertain food safety environments, the suppliers of food raw materials (FRM) are facing crucial food safety issues. Therefore, this article aims to probe the risk-averse attitude of FRM suppliers in the face changing marketing environments, in order to establish a decision-making theory as a standard reference for optimization methods to satisfy the maximum expected profit and utility function for the optimal order quantity of FRM suppliers' decision-making. We assume that urgent orders are permitted when products are out of stock, and surplus products will be sold at discounted prices, as based on the food safety circumstances and the differences of market acceptance (optimistic/normal/pessimistic), in order to affect the procurement costs and selling prices. The results of sensitivity analysis for the maximum expected profit show that the probability of imported FRM having no food safety problems when the external environment has no food safety problems is the most important parameter, with the importers fulfilling their responsibility for FRM source quality control. Meanwhile, a responsible attitude toward handling a crisis will reduce losses, transform the crisis into an opportunity, and win the trust of consumers, thereby, fostering corporate sustainability. Sensitivity analysis identifies the significant parameters that influence suppliers' maximum utility function, and provides a reference by which food-related companies may formulate sustainable business policies.

Keywords: risk management; optimal order quantity; risk aversion; food safety

1. Introduction

In the past few years, the food industry has grown steadily in the U.S.A, Europe, Southeast Asian countries, China, and Japan. In Taiwan, the gross domestic product (GDP) of the food industry was \$21.2 billion, of which 6.73 billion were imported products that shared 26.4% of the processed food market in 2014. It is estimated that the growth rate will reach 13.3% in the processed food industry from 2014 to 2019 (Li and Wang 2015). However, globally, successive issues of food safety have widely placed attention on food safety. The food industry is moving toward healthful, innovative, personalized, and more food safety controlled markets, which have made food safety examination-related businesses grow rapidly (Li and Wang 2015).

The United States Pharmacopeial Convention (USP 2014) enacted Guidance on Food Fraud Mitigation to prevent fake food fraud and reduce the food safety crisis. An overview of the global food industry aims to promote food labeling, self-inspection, and food traceability, in order to enhance the quality of products, improve the food consumption market and strengthen the management of supply chains for manufacturers (Li and Wang 2015).

The food industry in Taiwan mainly supplies the domestic market, while most FRM are imported. A series of food safety issues have made consumers worry about food processing and food additives, which have seriously affected the food processing business in Taiwan (Hsu et al. 2016).

The FRM suppliers are the source of the food processing business, and are responsible for food safety on the front line. When a food safety problem occurs, it will reduce consumers' trust and cause unnecessary panic, which will shrink the food consumption market and raise costs while seeking to solve the problem. Moreover, products with food safety issues flow across international borders, which will spread damage and loss to other countries (Calvin et al. 2002; Buzby 2001; Kotsanopoulos and Arvanitoyannis 2017).

To avoid unexpected loss and legal responsibility, as caused by imported products with food safety problems, FRM suppliers must put more effort and costs into their inspections. Preventing food safety problems from the external environment raises the issue of shortages in the supply of FRM, thus, the suppliers of FRM must profoundly consider the internal and external changes in the environment to establish an optimal order quantity to react to the needs of the market and maintain a profitable business to the best of their ability.

Food safety issues, whether attributed to the external or internal environment, affect the supply and demand of FRM and market share; suppliers may face restrictions on the shelf life or storage environment of FRM. Consequently, how to determine the optimal order quantity and conduct sound inventory cost management to increase or maintain market share are important issues for suppliers in terms of decision-making. The main purpose of this study is to establish a feasible mathematic model, and use that model as a basis for the batch and frequency of replenishing FRM for suppliers, as based on the market demand, which is affected by internal and external food safety. Therefore, it is necessary to increase the projected value of factories when FRM suppliers face the uncertainty of internal and external food safety.

2. Literature

2.1. Food Safety

Many elements influence food safety, such as global trade, socio-economic, and technological development, urbanization, and agricultural land use (Tirado et al. 2010). The issue of food safety in the supply chain is an ongoing problem. Food safety concerns and much-publicized food scares have intensified the United States' interest in the traceability of foods in the supply chain (Pouliot and Sumner 2008). Food safety issues of supply chains are a continual problem. While the US government has spent much effort and money on food production to secure food safety, numerous food-related illnesses contribute to deaths in the United States (Ahearn et al. 2016). According to the Center for Disease Control and Prevention (CDC 2018), it is estimated that each year 48 million people get sick from foodborne illnesses. The most common diseases caused by food are from the consumption of microbes, pesticides, or chemical additives, thus, the risk of food safety in the food supply chain has become an important issue (Food and Agriculture Organization of the United Nations 2011). While the risks cannot be completely eradicated, they could be diminished by taking the initiative in employing various positive solutions (Septiani et al. 2016).

Traditional food sampling and the food safety inspection system can no longer ensure that consumers will benefit from these procedures; therefore, modern food safety management and the threat to public health prevention systems should be connected. In the past ten years, food safety management has adopted a risk analysis framework as the basis of decision-making (Koutsoumanis and Aspridou 2016). The global food trade is continuously growing, and as global supply chains transport goods across the world, which link supply and demand over thousands of miles (Manzini et al. 2014), the expansion of the global food trade, the differences in food safety regulations, and standards in different countries have become clearer, and such differences in import and export countries could cause international food trade conflicts (Buzby and Mitchell 2003). Therefore, the Global Food Safety Initiative (GFSI) also proposes establishing a standard project that can be accepted by most retailers according to international food safety standards (Crandall et al. 2012). In addition, after a food safety issue occurs, consumers would buy fewer products from countries with food safety problems, and are ready to pay more to secure food safety (He et al. 2014).

Food safety is an experience feature: consumers cannot see if the food they are buying is free from bacterial contamination, toxic compounds, or other harmful dopants, thus, the reputation of the manufacturer becomes an important determinant (Adalja and Lichtenberg 2016). The protection of food safety in the current food supply chain can be easily compromised due to various obstacles and misunderstandings. Thus, a new approach, Good Nutritional Practices (GNP), is being used to manage food safety. Good Nutritional Practices, which includes consumer participation, is based on a model designed for goods flowing through the food supply chain (Herrera et al. 2016), and is important for rebuilding the food safety system.

2.2. Food Supply Chain Management (FSCM) and Optimal Order Quantity

Most FRM come from agriculture products, which are perishable, and the long process of the supply chain between farmers to consumers increases the risk of food safety problems (Septiani et al. 2016). Furthermore, farm products are usually affected by the weather, which makes the supply unsteady and the price unsettled. FRM suppliers that offer stable products and prices to the customers are as important as the establishment of a good SCM system to run the food business (Lee et al. 2012).

An effective way to solve the food safety problem is to enhance the management of food storage and strengthen the mutual comprehension of the importance of food safety between business and government (Pan 2016). Inventory management is a part of supply chain management that aims to minimize inventory cost. However, the most challenging part of procurement for buyers is to estimate the optimal order quantity for each purchase, while minimizing the inventory carrying costs and order costs (Rezaei 2016). Economic ordering quantity (EOQ) is the basic inventory management approach that attempts to reduce the cost of orders and purchase cycles (Bassin 1990).

There are many studies on optimizing pricing strategies in the financial and economic fields, e.g., Ho and Stoll (1981) explored optimized pricing to get the expected profit from the dealer's maximum utility function; Kunreuther and Richard (1971) explored the interrelationship between optimal pricing and inventory decisions for retailers who order goods from external distributors; Dammon and Spatt (1996) explored the optimal transaction and pricing of taxable securities with asymmetric capital gains tax and transaction costs. This article explores the optimized expected profit and minimal cost of inventory is risk-neutral decision-making; however, not all inventory planning is risk-neutral, means that many people are willing to sacrifice expected profits to reduce potential losses. It has been empirically shown that, in some high-profit products, decision makers show risk aversion behavior (Chen et al. 2007). Shu et al. (2015) investigated an effective inventory strategy for a risk-averse retailer facing unreliable supply and stochastic demand, and used the concave utility function to describe risk aversion, which provides the optimal order quantity to achieve effective control over supply risk. The classical EOQ model assumes that all products received from suppliers have perfect quality (El-Kassar 2009), and completely ignores buyers receiving imperfect products; while the EOQ model for imperfect products focuses mainly on full inspection to separate the imperfect products and maximize the buyer's expected total profit (Rezaei 2016). Salameh and Jaber (2000) and Shekarian et al. (2014) established a mathematic model which assumes that not all products with imperfect quality have defects, and imperfect products may be sold at a discounted price after selection. Chang and Lin (2011) indicated that the traditional EOQ model assumes that all stock parameters (e.g., unit costs, demand rates, installation costs, or holding costs) are unchanged. In fact, the costs of suppliers may change in part or wholly. If suppliers plan to raise prices, buyers may store more stock before the rise in prices (Ouyang et al. 2016).

Many previous scholars discussed the order strategy of the optimal order quantity according to the EOQ model, such as Chang et al. (2003); Chung et al. (2005); Kazemi et al. (2018); Dobson et al. (2017). Chung and Liao (2009) investigated the inventory strategy of optimal order quantity and the postponement of payments within the EOQ model. Giri and Sharma (2016) discovered that the best solution of the optimal order quantity is based on the trade term relationship from upstream, downstream, and the stock shortage allowance. Ouyang et al. (2016) investigated the optimal order strategy through cost analysis; when an order is limited and the defect rate of products is fixed, the rising price might affect the replenishment strategy. Chang et al. (2016) developed an EOQ model to maximize the total profit of the optimal order strategy for retailers, which included permission for payment postponement, defective products, and inspection errors. However, there is a lack of studies on the optimal order quantity with food safety issues.

3. Method

3.1. Optimization Methods

Van Asselt et al. (2017) indicated that food safety hazards may occur at various stages in the dairy supply chain. Food safety problems may originate from the soil, environmental pollution, chemical residue, or artificial additives in the production process, which are uncontrolled food safety problems from the external environment for individual FRM suppliers. Chemical hazards mainly arise at the dairy farm and accumulate during further processing, while the physical hazards are metal, glass, and plastic particles contaminated during processing. Some of the internal food safety problems occur from the FRM suppliers that are unable to manage the quality of imported FRM, which deteriorate during the process of transportation, storage, or human negligence in reproduction. Food manufacturers can suffer in several ways by unknowingly purchasing inferior or illegal raw materials (Moyer et al. 2017). Food safety problems may result from food fraud, such as adulteration or fake food. Fraud and crimes can result from the long distance or lack of physical contact between suppliers and manufacturing partners (Heinonen et al. 2017). Therefore, the general assumptions of the proposed model are defined as two factors in terms of the external and internal environments: meaning the food safety problems arising from the external environment and the internal food safety problems that refer to individual FRM suppliers.

This paper assumes that imported FRM can be sold directly or after blending and processing. This model assumes that optimistic/normal/pessimistic sales statuses are evaluated under several scenarios:

(1) The external environment and the individual FRM suppliers do not have food safety problems;
(2) The individual FRM suppliers have an internal food safety problem and the external environment does not have a food safety problem;
(3) The external environment has a food safety problem and the individual FRM suppliers do not have an internal food safety problem;
(4) Both the external environment and the individual FRM suppliers have food safety problems.

The parameters of the promoted production model are defined in Appendix A, Table A1.

A general decision theory is established to provide an optimization method for decision evaluation on the optimal order quantity at the maximum profit in terms of the changes in purchasing costs and sales prices in the above four situations. This article assumes that product costs and selling prices under different market environments will change; at the same time, importers are allowed to urgently process orders under out of stock issues, and surplus products will be sold at discounted prices. Under the importers' attitudes to risk aversion, mathematical models are established to meet the importers' maximum net profit and maximum utility function of the optimal order quantity decisions.

For the convenience of description, this model assumes that a food safety problem in the external environment may cause a change in the purchasing cost of FRM. It is assumed that the probability that products are made of FRM with no safety problem in the external environment is $A(0 \leq A \leq 1)$, while the probability that products are made of FRM with a safety problem in the external environment is $1 - A$. The probability that the imported FRM has no food safety problem is $B_s(0 \leq B_s \leq 1)$, while the probability that the imported FRM has a food safety problem is $1 - B_s$ when the external environment has no food safety problem. The probability that the imported FRM has no food safety problem is $B_u(0 \leq B_u \leq 1)$, while the probability that the imported FRM has a food safety problem is $1 - B_u$ when the external environment has a food safety problem.

Normally, the unit cost of imported FRM is C, and the unit sales price is P when the external environment and imported FRM have no food safety problems. The economic benefit is generated if natural restricted conditions are $P - C > 0$. The cost of imports may be affected when the imported FRM has a food safety problem. This article assumes that the optimal order quantity θ^* decision must be made in advance, and that the sales amount $\theta_S^S(j)$ has three market reactions: $\theta_s^s(o)$ (optimistic), $\theta_s^s(n)$ (normal), and $\theta_s^s(p)$ (pessimistic). The probabilities of these reactions are ρ_s^{so}, ρ_s^{sn}, and ρ_s^{sp}, respectively ($\rho_s^{so} + \rho_s^{sn} + \rho_s^{sp} = 1, 0 \leq \rho_s^{so} \leq 1, 0 \leq \rho_s^{sn} \leq 1, 0 \leq \rho_s^{sp} \leq 1$). $(P_s^s(j) - C) \times \min\{\theta_s^s(j), \theta^*\}$ indicates that sales profits are under the $\min\{\theta_s^s(j), \theta^*\}$. In case $\theta^* - \theta_S^S(j) \geq 0$ causes an inventory of the amounts of $\theta^* - \theta_S^S(j)$, this inventory can be sold at a discounted price P^d and generate profits of $(P_s^{ds}(j) - C) \times (\theta^* - \theta_s^s(j))$. In case $\theta^* - \theta_S^S(j) < 0$ causes a shortage of $\theta_S^S(j) - \theta^*$, this shortage can be remedied by making an urgent order from other suppliers at an urgent order cost of $W_s^s(j) > C,\ j = o, n, p$ and generate profits of $(P_s^s(j) - W_s^s(j)) \times \left(\theta_S^S(j) - \theta^*\right)$. Net profits $\pi_{ss}^j(\pi_s^s(j); \theta^*)$ of the three market statuses (o, n, p) under both the external and internal environments with no food safety problems are, as follows:

$$\begin{aligned} \pi_{ss}^j(\theta_s^s(j); \theta^*) \ &= (P_s^s(j) - C) \times \min\{\theta_s^s(j), \theta^*\} + (P^d{}_s^s(j) - C) \times (\theta^* - \theta_s^s(j)) \times \mathrm{I}(\theta^* - \theta_s^s(j) \geq 0) \\ &+ (P_s^s(j) - W_s^s(j)) \times (\theta_s^s(j) - \theta^*) \times \mathrm{I}(\theta_s^s(j) - \theta^* \geq 0), j = o, n, p \end{aligned} \tag{1}$$

where two mutual index functions are defined as:

$$\mathrm{I}(\theta^* - \theta_s^s(j) \geq 0) = \begin{cases} 1, & \text{if } \theta^* - \theta_s^s(j) \geq 0 \\ 0, & otherwise \end{cases} \text{and} \mathrm{I}(\theta_s^s(j) - \theta^* \geq 0) = \begin{cases} 1, & \text{if } \theta_s^s(j) - \theta^* \geq 0 \\ 0, & otherwise \end{cases}$$

If the external environment has no food safety problem, but the imported FRM does, the sales amount $\theta_s^u(j)$ may have three market reactions: $\theta_s^u(o)$ (optimistic), $\theta_s^u(n)$ (normal), and $\theta_s^u(p)$ (pessimistic), and their probabilities are ρ_s^{uo}, ρ_s^{un}, and ρ_s^{up}, respectively ($\rho_s^{uo} + \rho_s^{un} + \rho_s^{up} = 1, 0 \leq \rho_s^{uo} \leq 1$, $0 \leq \rho_s^{un} \leq 1, 0 \leq \rho_s^{up} \leq 1$). It is assumed that the imported FRM can be immediately handled in the case of a food safety problem, but the unit cost of the imported FRM will increase by $(1 + \varepsilon_s^{uc})C$. ε_s^{uc} is the handling cost for each increase and imported FRM with a food safety problem, which should be destroyed with no residual value, while the shortage can be remedied by making an urgent order from other suppliers at an urgent order cost of $W_s^s(j) > C,\ j = o, n, p$. Net profits $\pi_{su}^j(\theta_s^u(j); \theta^*)$ of the three market statuses (o, n, p) under an external environment with no food safety problem and imported FRM with a food safety problem are, as follows:

$$\pi_{su}^j(\theta_s^u(j); \theta^*) = (-(1 + \varepsilon_s^{uc}) \times C) \times \theta^* + (P_s^u(j) - \ W_s^u(j)) \times \theta_s^u(j)), j = o, n, p \tag{2}$$

If the external environment has a food safety problem, but the imported FRM does not, the sales amount $\theta_u^s(j)$ may have three market reactions: $\theta_u^s(o)$ (optimistic), $\theta_u^s(n)$ (normal), and $\theta_u^s(p)$ (pessimistic), and the probabilities are ρ_u^{so}, ρ_u^{sn}, and ρ_u^{sp}, respectively ($\rho_u^{so} + \rho_u^{sn} + \rho_u^{sp} = 1, 0 \leq \rho_u^{so} \leq 1$, $0 \leq \rho_u^{sn} \leq 1, 0 \leq \rho_u^{sp} \leq 1$). Due to the change in market demand, the unit price of safe FRM is increased by $(1 + \varepsilon_u^{sp})P_u^s(j)$, in which ε_u^{sp} is a unit of premium. Here, for inventory and shortages, the same assumptions as explained in the previous paragraph apply. The net profit $\pi_{us}^j(\theta_u^s(j); \theta^*)$ of the three market statuses (o, n, p) in an external environment with a food safety problem and imported FRM with no food safety problem are, as follows:

$$\begin{aligned} \pi_{us}^j(\theta_u^s(j); \theta^*) = \ &((1 + \varepsilon_u^{sp}) \times P_u^s(j) - C) \times \min\{\theta_u^s(j), \theta^*\} + (P^d{}_u^s(j) - C) \times (\theta^* - \theta_u^s(j)) \times \mathrm{I}(\theta^* - \theta_u^s(j) \geq 0) \\ &+ (P_u^s(j) \times (1 + \varepsilon_u^{sp}) - \mathrm{W}_u^s(j)) \times (\theta_u^s(j) - \theta^*) \times \mathrm{I}(\theta_u^s(j) - \theta^* \geq 0),\ j = o, n, p \end{aligned} \tag{3}$$

where two mutual index functions are defined as:

$$\mathrm{I}(\theta^* - \theta_u^s(j) \geq 0) = \begin{cases} 1, & \text{if } \theta^* - \theta_u^s(j) \geq 0 \\ 0, & otherwise \end{cases} \text{and} \mathrm{I}(\theta_u^s(j) - \theta^* \geq 0) = \begin{cases} 1, & \text{if } \theta_u^s(j) - \theta^* \geq 0 \\ 0, & otherwise \end{cases}$$

If the external environment and the imported FRM have food safety problems, the sales amount $\theta_u^u(j)$ may have three market reactions: $\theta_u^u(o)$ (optimistic), $\theta_u^u(n)$ (normal), and $\theta_u^u(p)$ (pessimistic), and the probabilities are ρ_u^{uo}, ρ_u^{un}, and ρ_u^{up}, respectively ($\rho_u^{uo} + \rho_u^{un} + \rho_u^{up} = 1$, $0 \leq \rho_u^{uo} \leq 1$, $0 \leq \rho_u^{un} \leq 1$, $0 \leq \rho_u^{up} \leq 1$). Concerning regulations and the market, imported FRM with a food safety problem should be destroyed with no residual value, while the shortage can be remedied by making an urgent order from other suppliers at an urgent order cost of $W_u^u(j) > C,\ j = o, n, p$. Imported FRM with a food safety problem should be handled immediately, with the unit cost of importing is increased to $(1 + \varepsilon_u^{uc})C$, where ε_u^{uc} is a unit of disposal cost for each increase. The net profits $\pi_{uu}^j(\theta_u^u(j); \theta^*)$ of the three market statuses (o, n, p) in both the external environment and the imported FRM with food safety problems are, as follows:

$$\pi_{uu}^j(\theta_u^u(j); \theta^*) = (-(1 + \varepsilon_u^{uc}) \times C) \times \theta^* + (P_u^u(j) - W_u^u(j)) \times \theta_u^u(j)), j = o, n, p. \tag{4}$$

The expected revenue is $\pi_{ss}(\theta^*)$:

$$\pi_{ss}(\theta^*) = \sum_{j=o,n,p} \rho_s^{sj} \times \pi_{ss}^j(\theta_s^s(j); \theta^*), \tag{5}$$

The expected revenue is $\pi_{su}(\theta^*)$:

$$\pi_{su}(\theta^*) = \sum_{j=o,n,p} \rho_s^{uj} \times \pi_{su}^j(\theta_s^u(j); \theta^*), \tag{6}$$

The expected revenue is $\pi_{us}(\theta^*)$:

$$\pi_{us}(\theta^*) = \sum_{j=o,n,p} \rho_u^{sj} \times \pi_{us}^j(\theta_u^s(j); \theta^*), \tag{7}$$

The expected revenue is $\pi_{uu}(\theta^*)$:

$$\pi_{uu}(\theta^*) = \sum_{j=o,n,p} \rho_u^{uj} \times \pi_{uu}^j(\theta_u^u(j); \theta^*), \tag{8}$$

The probability that the imported FRM has no food safety problem is $B_s (0 \leq B_s \leq 1)$ when the external environment has no food safety problem.

Thus, to calculate the expected revenue $\pi_s(\theta^*)$:

$$\pi_s(\theta^*) = B_s \times \pi_{ss}(\theta^*) + (1 - B_s) \times \pi_{su}(\theta^*), \tag{9}$$

The probability that the imported FRM has no food safety problem is $B_u (0 \leq B_u \leq 1)$ when the external environment has a food safety problem.

The expected revenue is $\pi_u(\theta^*)$:

$$\pi_u(\theta^*) = B_u \times \pi_{us}(\theta^*) + (1 - B_u) \times \pi_{uu}(\theta^*), \tag{10}$$

The probability of the external environment without a food safety problem is $A(0 \leq A \leq 1)$. The initial objective function of the optimal order quantity θ^* of the imported FRM is to attain the maximum expected net profits $\pi(\theta^*)$:

$$\pi(\theta^*) = \max_{\theta^*}\{A \times \pi_s(\theta^*) + (1 - A) \times \pi_u(\theta^*)\}. \tag{11}$$

The derivative function is set to zero to derive the following equation:

$$\frac{\frac{d\pi_s(\theta^*)}{d\theta^*}}{\frac{d\pi_u(\theta^*)}{d\theta^*}} = -\frac{1 - A}{A}. \tag{12}$$

To find the maximum value, the criteria for the second derivative of less than zero must be met to derive the following equation:

$$\frac{\frac{d^2\pi_s(\theta^*)}{d\theta^{*2}}}{\frac{d^2\pi_u(\theta^*)}{d\theta^{*2}}} < -\frac{1 - A}{A}. \tag{13}$$

After some manipulations, the following is obtained:

$$\begin{gathered}\frac{\frac{d\pi_s(\theta^*)}{d\theta^*}}{\frac{d\pi_u(\theta^*)}{d\theta^*}} = \frac{B_s\frac{d\pi_{ss}(\theta^*)}{d\theta^*}+(1-B_s)\frac{d\pi_{su}(\theta^*)}{d\theta^*}}{B_u\frac{d\pi_{us}(\theta^*)}{d\theta^*}+(1-B_u)\frac{d\pi_{uu}(\theta^*)}{d\theta^*}} = \\ \frac{B_s\sum\limits_{j=o,n,p}\rho_s^{sj}\left(\frac{d\pi_{ss}^j(\theta_S^s(j);\theta^*)}{d\theta^*}\right)+(1-B_s)\sum\limits_{j=o,n,p}\rho_s^{uj}\left(\frac{d\pi_{su}^j(\theta_S^u(j);\theta^*)}{dQ^*}\right)}{B_u\sum\limits_{j=o,n,p}\rho_u^{sj}\left(\frac{d\pi_{us}^j(\theta_u^s(j);\theta^*)}{d\theta^*}\right)+(1-B_u)\sum\limits_{j=o,n,p}\rho_u^{uj}\left(\frac{d\pi_{uu}^j(\theta_u^u(j);\theta^*)}{d\theta^*}\right)} = -\frac{1-A}{A}\end{gathered} \tag{14}$$

The relevant research framework is shown in Figure 1.

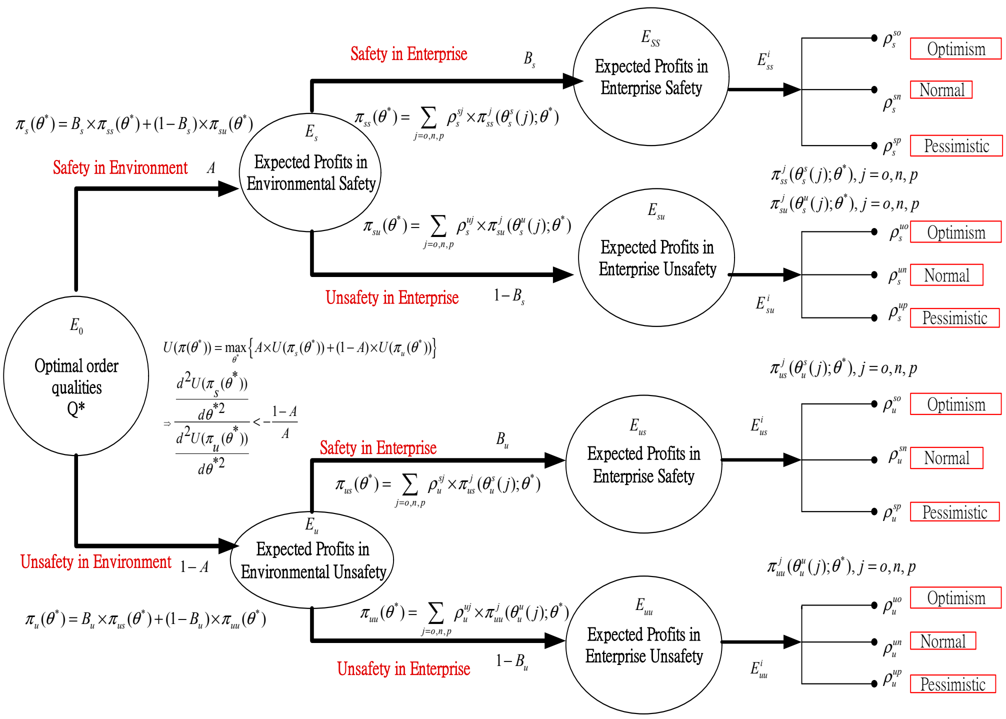


Figure 1. The optimal order quantity framework of the food safety problem under the condition of environmental and corporate uncertainty.

3.2. Risk Aversion Concept

This paper assumed: (1) the decision maker is risk-averse with its expected net profits; (2) the risk-averse utility function of the decision maker is represented by a logarithmic function. The risk-averse utility function $r(\pi) = -(U''(\pi)/U'(\pi))$ should be greater than zero for the logarithmic function to satisfy the risk averse condition.; (3) h is the parameter of the basic utility function, where the FRM supplier runs the business of imported FRM without considering the profit and loss, and $h + \pi > 0$ is the natural constraint; (4) if $h + \pi \leq 0$, the FRM supplier will terminate the related business of imported FRM. In this model, the objective of the function is to solve the optimal order quantity (θ^*) of imported FRM at the maximum net profit within a risk-averse attitude. Due to the food safety problem in the external environment, the sense of satisfaction for expected profit X will be (X) times greater when there is no food safety problem in the external environment of FRM suppliers with a risk aversion attitude. Therefore, it is assumed as $U(\pi_s(\theta^*)) = \log(\pi_s(\theta^*) + h)$, $U(\pi_u(\theta^*)) = \mathrm{X} \times (\log(\pi_u(\theta^*) + h))$; X is the multiple of the sense of satisfaction for the expected profit under the external environment with a food safety problem, as compared to one with no food safety problem. Namely, in the mutual influence of the benefits and costs, meaning how to determine the optimal order quantity θ^* in the case of food safety risk in the external environment, or imported FRM under the risk aversion concept, is one of the most important aspects for establishing the model.

If the decision-maker is risk-averse toward a net profit with $U(\pi_s(\theta^*)) = \log(\pi_s(\theta^*) + h)$, then $U(\pi_u(\theta^*)) = \mathrm{X} \times (\log(\pi_u(\theta^*) + h))$.

The initial objective function of the optimal order quantity θ^* of the imported FRM is to attain the maximum expected net profits $U(\pi(\theta^*))$:

$$U(\pi(\theta^*)) = \max_{\theta^*}\{A \times U(\pi_s(\theta^*)) + (1 - A) \times U(\pi_u(\theta^*))\}. \tag{15}$$

A derivative function is equal to zero to derive the following equation:

$$\frac{\frac{dU(\pi_s(\theta^*))}{d\theta^*}}{\frac{dU(\pi_u(\theta^*))}{d\theta^*}} = -\frac{1-A}{A}. \tag{16}$$

To find the maximum value, the criteria for the second derivative of less than zero must be met to derive the following equation:

$$\frac{\frac{d^2U(\pi_s(\theta^*))}{d\theta^{*2}}}{\frac{d^2U(\pi_u(\theta^*))}{d\theta^{*2}}} < -\frac{1-A}{A}. \tag{17}$$

Furthermore, Equation (16) can be reduced to the following form:

$$E(\theta^*) \equiv B_s \sum_{j=o,n,p} \rho_s^{sj} \left(\begin{array}{l} \frac{(P_s^s(j) - C) \times \frac{d\min\{\theta_s^s(j),\theta^*\}}{d\theta^*} + (P^{d}{}_s^s(j) - C) \times \frac{d(\theta^* - \theta_s^s(j)) \times \mathrm{I}(\theta^* - \theta_s^s(j) \geq 0)}{d\theta^*}}{\pi_{ss}^j(\theta^*)} \\ + \frac{(P_s^s(j) - W_s^s(j)) \times \frac{d(\theta_s^s(j) - \theta^*) \times \mathrm{I}(\theta_s^s(j) - \theta^* \geq 0)}{d\theta^*}}{\pi_{ss}^j(\theta^*)} \end{array} \right) \text{ and}$$
$$+ (1 - B_s) \sum_{j=o,n,p} \rho_s^{uj} \left(\frac{(-(1 + \varepsilon_s^{uc}) \times C + (P_s^u(j) - W_s^u(j)) \times \frac{d(\theta_s^u(j))}{d\theta^*}}{\pi_{su}^j(\theta^*)} \right)$$

$$F(\theta^*) \equiv B_u \sum_{j=o,n,p} \rho_u^{sj} \left(\begin{array}{l} \frac{((1+\varepsilon_u^{sp}) \times P_u^s(j) - C) \times \frac{d\min\{\theta_u^s(j),\theta^*\}}{d\theta^*}}{\pi_{us}^j(\theta^*)} \\ + \frac{(P_u^{ds}(j) - C) \times \frac{d(\theta^* - \theta_u^s(j)) \times \mathrm{I}(\theta^* - \theta_u^s(j) \geq 0)}{d\theta^*}}{\pi_{us}^j(\theta^*)} \\ + \frac{(P_u^s(j) - W_u^s(j)) \times \frac{d(\theta_u^s(j) - \theta^*) \times \mathrm{I}(\theta_u^s(j) - \theta^* \geq 0)}{d\theta^*}}{\pi_{us}^j(\theta^*)} \end{array} \right)$$
$$+ (1 - B_u) \sum_{j=o,n,p} \rho_u^{uj} \left(\frac{(-(1 + \varepsilon_u^{uc}) \times C + (P_u^u(j) - W_u^u(j)) \times \frac{d(\theta_u^u(j))}{d\theta^*}}{\pi_{uu}^j(\theta^*)} \right)$$

Then, the optimal order quantity θ^* satisfies Equation (18):

$$\frac{E(\theta^*)}{F(\theta^*)} = -\frac{1-A}{A}. \quad (18)$$

4. Numerical Example and Sensitivity Analysis

To facilitate numerical and sensitivity analyses, the FRM in this study indicates one specific FRM. To find the maximum utility functions that affect the expected profits of FRM suppliers facing a risk aversion attitude, and undertake a numerical example, this manuscript carries out sensitivity analysis with important parameters under the consideration of the reoccurring probability of a food safety problem both in the external environment and from FRM suppliers.

4.1. Numerical Example

Based on the assumed parameters in Table 1 and employing Polymath software to analyze the numerical example, the results show that, the probability of no food safety problems occurring in the external environment is A, 0.7; without food safety problems in the external environment and FRM, it is B_s, 0.8; the probability of food safety problems in the external environment, but not in the FRM supplier, is B_u, 0.7; the solving cost for FRM suppliers with a food safety problem is $\varepsilon_s^{uc}/\varepsilon_u^{uc}$, 0.2; the ratio of the premium with food safety problems in the external environment, but not with the FRM suppliers, is ε_u^{sp}, 0.3.

The optimal order quantity is $\theta^* = 6.00 \times 10^4$; the best expected profit is $\pi(\theta^*) = 1.79 \times 10^5$ and the maximum utility function is $U(\pi(\theta^*)) = 7.417735$. The numerical example is shown in Table 2.

Table 1. All assigned parameters for the proposed model with numerical examples.

Parameters	A	B_s	B_u	C	P	ε_s^{uc}	ε_u^{sp}	ε_u^{up}	ε_u^{uc}
Assigned Values	0.7	0.8	0.7	400	500	0.2	0.3	0.3	0.2
Parameters	$P_s^s(o)$	$P_s^s(n)$	$P_s^s(p)$	$P_s^u(o)$	$P_s^u(n)$	$P_s^u(p)$	$P_u^s(o)$	$P_u^s(n)$	$P_u^s(p)$
Assigned Values	510	500	490	510	500	490	510	500	490
Parameters	$P_u^u(o)$	$P_u^u(n)$	$P_u^u(p)$	ρ_s^{so}	ρ_s^{sn}	ρ_s^{uo}	ρ_s^{un}	ρ_u^{so}	ρ_u^{sn}
Assigned Values	530	510	500	0.6	0.3	0.3	0.4	0.2	0.5
Parameters	ρ_u^{uo}	ρ_u^{up}	X	$P_s^{ds}(o)$	$P_s^{ds}(n)$	$P_s^{ds}(p)$	$P_s^{du}(o)$	$P_s^{du}(n)$	$P_s^{du}(p)$
Assigned Values	0.1	0.7	1.3	480	460	440	420	400	380
Parameters	$P_u^{ds}(o)$	$P_u^{ds}(n)$	$P_u^{ds}(p)$	$P_u^{du}(o)$	$P_u^{du}(n)$	$P_u^{du}(p)$	$W_s^s(o)$	$W_s^s(n)$	$w_s^s(p)$
Assigned Values	490	470	450	420	400	380	490	480	470
Parameters	$W_s^o(o)$	$W_s^u(n)$	$W_s^u(p)$	$W_u^s(o)$	$W_u^s(n)$	$W_u^s(p)$	$W_u^u(o)$	$W_u^u(n)$	$W_u^u(p)$
Assigned Values	490	480	470	490	480	470	500	490	480
Parameters	$\theta_s^s(o)$	$\theta_s^s(n)$	$\theta_s^s(p)$	$\theta_s^u(n)$	$\theta_s^u(p)$	$\theta_u^s(o)$	$\theta_u^s(n)$	$\theta_u^s(p)$	$\theta_u^u(o)$
Assigned Values	60,000	50,000	40,000	30,000	20,000	65,000	55,000	45,000	40,000
Parameters	$\theta_u^u(n)$	$\theta_u^u(p)$	$\theta_s^u(o)$						
Assigned Values	30,000	20,000	35,000						

Table 2. Analysis of numerical examples.

Parameters	Numerical Values	Numerical Values	Numerical Values	Numerical Values	Numerical Values
θ^*	5.00×10^4	5.50×10^4	6.00×10^4	6.50×10^4	7.00×10^4
$\pi(\theta^*)$	-4.02×10^5	-2.41×10^5	1.79×10^5	4.49×10^5	9.25×10^5
$U(\pi(\theta^*))$	6.973095	7.275677	7.417735	7.345711	7.383716

4.2. Sensitivity Analysis of the Model

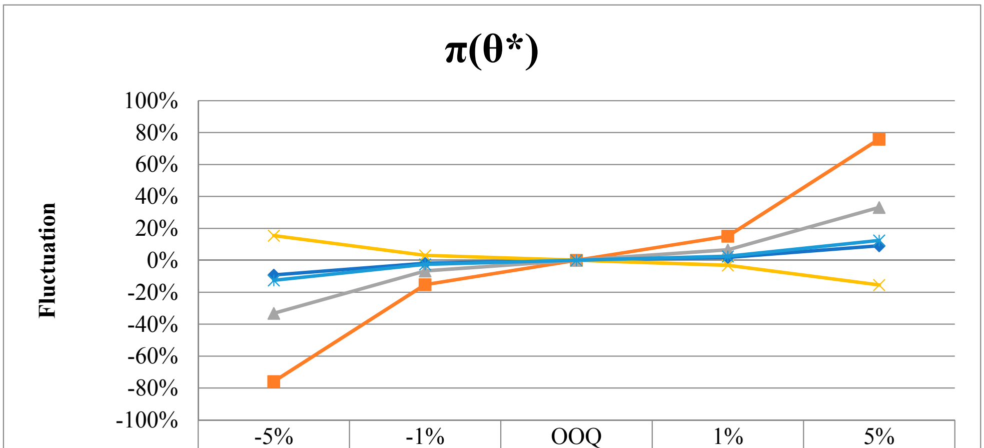
This study assumes all the parameters in Table 1 and suggestions from experienced FRM suppliers; thus, we select A, B_s, B_u, $\varepsilon_s^{uc}/\varepsilon_u^{uc}$, and ε_u^{sp} as the important parameters for sensitivity analysis. This is to compare the influence of the threshold of all the parameters in order to determine the important effective factors to satisfy the maximum profit $\pi(\theta^*)$ and the maximum utility function $U(\pi(\theta^*))$ under the condition of FRM suppliers with a risk aversion attitude. The variation ratio of each parameter is $\pm 1\%$ and $\pm 5\%$. The changes of all parameters are shown in Table 3.

Table 3. Parameter variations.

Parameter \ Variation	−5%	−1%	1%	5%
A	0.65	0.69	0.71	0.75
B_s	0.75	0.79	0.81	0.85
B_u	0.65	0.69	0.71	0.75
$\varepsilon_s^{uc}/\varepsilon_u^{uc}$	0.15	0.19	0.21	0.25
ε_u^{sp}	0.25	0.29	0.31	0.35

According to Figure 2, sensitivity analysis for the best expected net profit shows that other conditions remain the same, and the important parameter that affects the best expected net profit for FRM suppliers is probability B_s of the imported FRM with no food safety problems when the external environment has no food safety problems. When the probability of B_s increases by 1%, the best net profit $\pi(\theta^*)$ will increase by 15.17%; when the probability of B_s increases by 5%, the best net profit $\pi(\theta^*)$ will substantially increase by 75.88%. However, when the probability of B_s is reduced by 1%, $\pi(\theta^*)$ will decrease by 15.22%; when the probability of B_s is reduced by 5%, the best net profit $\pi(\theta^*)$ will substantially decrease by 75.92%.

The second most-significant factor is the B_u of a food safety problem occurring in the external environment, but not among the suppliers. When the probability of B_u increases by 1% and 5%, $\pi(\theta^*)$ will increase by 6.60% and 33.13%, respectively. When B_u decreases by 1% and 5%, $\pi(\theta^*)$ decreases by 6.66% and 33.18%, respectively. For parameters A, $\varepsilon_s^{uc}/\varepsilon_u^{uc}$, and ε_u^{sp}, their impacts on the suppliers' expectations of maximum profits are $\varepsilon_s^{uc}/\varepsilon_u^{uc}$, ε_u^{sp} and A, respectively. When the parameter values fluctuate by $\pm 1\%$, $\pi(\theta^*)$ fluctuates between $\pm 1.79\%$ and $\pm 3.13\%$, while a $\pm 5\%$ fluctuation causes $\pi(\theta^*)$ to fluctuate between $\pm 9.12\%$ and $\pm 15.45\%$.



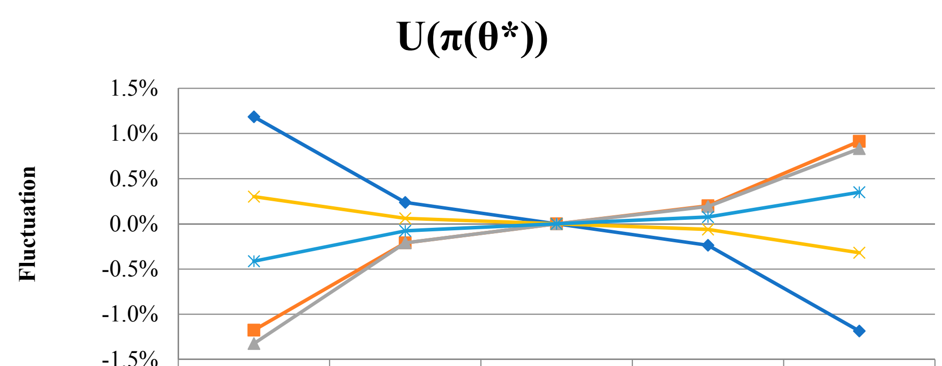
	-5%	-1%	OOQ	1%	5%
A	-9.18%	-1.85%	0%	1.79%	9.12%
Bs	-75.92%	-15.22%	0%	15.17%	75.88%
Bu	-33.18%	-6.66%	0%	6.60%	33.13%
εuuc/εsuc	15.44%	3.08%	0%	-3.13%	-15.44%
εup	-12.53%	-2.52%	0%	2.46%	12.48%

Figure 2. Sensitivity analysis of parameter changes for maximum net profits.

As Figure 3 shows, the results of sensitivity analysis on the utility function indicates that, when all other conditions are unchanged, the most significant parameter affecting the suppliers' maximum utility function $U(\pi(\theta^*))$ is probability A of no food safety problems occurring in the external environment increases by 1%, while $U(\pi(\theta^*))$ decreases by 0.24%, and when probability A increases by 5%, $U(\pi(\theta^*))$ decreases by 1.19%. However, when probability A decreases by 1%, it increases $U(\pi(\theta^*))$ by 0.28%, and when probability A decreases by 5%, $U(\pi(\theta^*))$ increases by 1.185%, and also when the probability B_u of a food safety problem occurring in the external environment, but not among the suppliers. When the probability of B_u increases by 1% and 5%, $U(\pi(\theta^*))$ will increase by 0.19% and 0.83% accordingly; when B_u reduces by 1% and 5%, $U(\pi(\theta^*))$ will reduce by 0.21% and 1.32%, respectively. When a food safety problem occurs in the external environment, consumers will worry about the effect of food safety problems on their health, and will eat out less often in order to consume less processed foods. The behavior of consumers has seriously affected the food industry and made the suppliers pessimistic about their profits. Therefore, when a food safety problem occurs in the external environment, the profit that the suppliers have practically gained will be more satisfactory than they had expected.

The next most-significant factor is probability B_s of imported FRM having no food safety problems when the external environment has no food safety problems. When the probability of B_s increases by 1%, $U(\pi(\theta^*))$ will increase by 0.20%; when the probability of B_s increases by 5%, the best net profit $U(\pi(\theta^*))$ will increase by 0.91%. However, when the probability of B_s is reduced by 1%, $U(\pi(\theta^*))$ will decrease by 0.21%; when the probability of B_s is reduced by 5%, $U(\pi(\theta^*))$ will decrease by 1.176%. For parameters, $\varepsilon_u^{sc}/\varepsilon_u^{uc}$ and ε_u^{sp}, when the parameter values fluctuate by $\pm 1\%$, $U(\pi(\theta^*))$ fluctuates between $\pm 0.06\%$ and $\pm 0.08\%$, while a $\pm 5\%$ fluctuation causes $U(\pi(\theta^*))$ to fluctuate between $\pm 0.41\%$ and $\pm 0.30\%$.

The result of the above analysis shows a significant difference between the influential factor of the utility function of the satisfactory expected maximum net profit for FRM suppliers with a risk aversion attitude and the important parameter of maximum net profit for FRM suppliers without a risk aversion attitude. The important influential parameter is B_s without considering the risk aversion attitude, while B_u is the important influential parameter with a risk aversion attitude when a food safety problem occurs in the external environment, but the suppliers do not have the problem. The suppliers should be more cautious when a food safety problem occurs in the external environment, and should take a proactive attitude to prevent and reduce the probability of food safety problems occurring with imported FRM for the supplier.



	-5%	-1%	OOQ	1%	5%
A	1.18%	0.24%	0%	-0.24%	-1.18%
Bs	-1.18%	-0.21%	0%	0.20%	0.91%
Bu	-1.32%	-0.21%	0%	0.19%	0.83%
εuuc/εsuc	0.30%	0.06%	0%	-0.06%	-0.32%
εup	-0.41%	-0.08%	0%	0.07%	0.35%

Figure 3. Sensitivity analysis of parameter changes for the utility function.

5. Discussion and Conclusions

5.1. Discussion

This paper focused on the construction of the optimal order quantity model to obtain the highest revenue via the introduction of risk aversion in uncertain food safety environments; when the suppliers of FRM are faced with (1) food safety problems due to the market environment; (2) food safety problems due to themselves under the three sales conditions of optimistic, pessimistic, and normal markets, when it is allowed to purchase urgent orders when the goods are out of stock, and when the remaining stocks are sold at a discount. In addition to exploring the maximum profit of the FRM suppliers, this paper simultaneously introduced the utility function, as well as the financial economic topics related to corporate value and risk management, which differ from the discussion of optimal order quantity and pricing models by Polatoglu (1991) from a single system inventory model; however, it is consistent with the pricing of the maximum utility function and the concept of the optimal order quantity of Agrawal and Seshadri (2000) in exploring the uncertainties of consumer demand.

Good risk management can add the value of the enterprise (MacKay and Moeller 2007; Haushalter et al. 2002). The mostly important risk management issues and basic solution of maintaining sustainable business for FRM suppliers is to defend food safety which means the suppliers should take the responsibility of defending food safety from the origin of the product and keep products with questionable food safety issues out of the supply chain, thereby, reducing the chance of a possible crisis, enhancing the maximum utility function for suppliers, and benefitting the development of the entire food industry.

5.2. Research Limitation

This article investigated the effect of food consumption markets from the consumer's perspective of the food safety issue, rather than that of food safety experts. Due to the long supply chain of FRM, their supply is affected by many factors, such as climate, origin, laws and regulations, the overall economic environment, and human and natural disasters. The limitation of developing the mathematical model in this study is not taking into account the uncertain factors that cannot be quantified into the model. This article only discusses the decision-making of the optimal quantity orders under different food safety environments, various marketing conditions, and individual suppliers with the risk aversion attitude, thus, it is suggested that future researchers could consider other important variations.

5.3. Conclusions

The result of sensitivity analysis indicates that the probability of imported FRM having no food safety problems when the external environment has no food safety problem is an important parameter of the maximum expected net profit. The results of this study are in accordance with Calvin et al. (2002), mean that if manufacturers provide consumers with good quality and safe food, and ensure that food trade does not create food safety risks, consumers will be willing to pay higher prices, thereby, increasing corporate profitability; as well as the belief of Salin (2000), mean that the probability of food safety issues occurring will affect the value of the enterprise choice. Due to the frequency of food safety problems in recent years, consumers are more concerned about food safety. When food safety problems accrue, it causes commodity losses and liability, ruins the enterprise's reputation and image, and may even cause business difficulties and the risk of collapse. FRM suppliers should fulfill their responsibilities for FRM source quality control.

It is the obligation of all FRM suppliers to recall all problematic products when they find products with food safety problems. Solving these problems not only guarantees food safety for consumers, it also reduces the handling costs for suppliers. A positive and responsible attitude towards handling a crisis will reduce losses, transform the crisis into an opportunity, and help to win the trust of consumers to maintain sustainable business.

5.4. Implications for Practice

The decision of batch order quantity for a supplier will affect their financial revenue and sustain their business. Meanwhile, establishing an instant supply system assists with the management of good relationships with customers, and offers stable products for individual manufacturers to establish trustworthy relationships. This article establishes a decision theory and optimization methods for FRM suppliers with a risk aversion attitude, in order to determining the optimal order quantity within different external food safety environments. Based on sensitivity analysis, this study discovered the key important parameters of the utility function of the maximum profit that affects FRM suppliers.

Due to the long supply chain of FRM, FRM suppliers should consider the external environment, the financial condition of suppliers, and other factors, in order to reduce the business cost of purchasing, storing, transporting, and negotiation, as well as moderate their cash flow and enhance their stock rotation through proper judgment of their batch replenishment strategy. In environments with uncertain food safety, consumers are concerned about food safety. FRM suppliers should consider shortening the food supply chain, reducing food mileage, and adopting local food raw materials to reduce the risks and costs that may arise from the FRM trade process.

Markets and consumers react negatively to perceived food safety issues, which cause suppliers to review their internal food safety environments. The suppliers' attitude towards perceiving food safety issues significantly affects their reputation and brand image, especially when the issues can be linked to their products, thus, this article serves as a reference for food-related companies to develop sustainable business policies.

This article introduces the topic of general risk management from different angles. Different from the research methods of general financial and economic research, it can be used as a reference for other analytical methods.

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Appendix A

Table A1. Parameter definitions.

Parameter	Definition
A	The probability of FRM with no safety problems in the external environment
B_s	The probability that the imported FRM have no food safety problems when the external environment has no food safety problems
B_u	The probability that the imported FRM have no food safety problems when the external environment has food safety problems
C	The unit cost of imported FRM
P	The unit sales price of imported FRM
j	Three market reactions. Optimistic (o), normal (n), and pessimistic (p)
$P_s^s(j)$	The unit sales price of three market reactions when the external environment and imported FRM have no food safety problems
$P_s^u(j)$	The unit sales price of three market reactions (optimistic, normal, and pessimistic) when the external environment has no food safety problems, but the imported FRM has a food safety problem

Table A1. *Cont.*

Parameter	Definition
$P_u^s(j)$	The unit sales price of three market reactions (optimistic, normal, and pessimistic) when the external environment has a food safety problem and the imported FRM has no food safety problem
$P_u^u(j)$	The unit sales price of three market reactions (optimistic, normal, and pessimistic) when the external environment and imported FRM have food safety problems
ε_s^{uc}	The handling cost for each rise, when the external environment has no food safety problem, but the imported FRM has a food safety problem
ε_u^{sp}	The unit of premium when the external environment has a food safety problem, but the imported FRM has no food safety problem
ε_u^{uc}	The unit of disposal cost for each increase when the external environment and the imported FRM have food safety problems
ρ_s^{sj}	The probability of three market reactions (optimistic, normal, and pessimistic) when the external environment and imported FRM have no food safety problems
ρ_s^{uj}	The probability of three market reactions (optimistic, normal, and pessimistic) when the external environment has no food safety problem, but the imported FRM has a food safety problem
ρ_u^{sj}	The probability of three market reactions (optimistic, normal, and pessimistic) when the external environment has a food safety problem, but the imported FRM has no food safety problem
ρ_u^{uj}	The probability of three market reactions (optimistic, normal, and pessimistic) when the external environment and the imported FRM have food safety problems
X	The multiple rewards for the suppliers of FRM in relation to the expectation of net income when the external environment has a food safety problem, as compared to the external environment with no food safety problem
h	The parameter of the basic utility function, where the FRM supplier runs the business of imported FRM without considering profit and loss
$P_s^{ds}(j)$	The discounted price when the external environment and the imported FRM have no food safety problems with three market reactions (optimistic, normal, and pessimistic)
$P_s^{du}(j)$	The discounted price when the external environment has no food safety problem, but the imported FRM has a food safety problem with three market reactions (optimistic, normal, and pessimistic)
$P_u^{ds}(j)$	The discounted price when the external environment has a food safety problem, but the imported FRM has no food safety problem with three market reactions (optimistic, normal, and pessimistic)
$P_u^{du}(j)$	The discounted price when the external environment and the imported FRM have food safety problems with three market reactions (optimistic, normal, and pessimistic)
$W_s^s(j)$	The urgent order cost when the external environment and imported FRM have no food safety problems with three market reactions (optimistic, normal, and pessimistic)
$W_s^u(j)$	The urgent order cost when the external environment has no food safety problem, but the imported FRM has a food safety problem with three market reactions (optimistic, normal, and pessimistic)
$W_u^s(j)$	The urgent order cost when the external environment has a food safety problem, but the imported FRM has no food safety problem with three market reactions (optimistic, normal, and pessimistic)
$W_u^u(j)$	The urgent order cost when the external environment and the imported FRM have food safety problems with three market reactions (optimistic, normal, and pessimistic)

Table A1. *Cont.*

Parameter	Definition
$\theta_s^s(j)$	The sales amount when the external environment and the imported FRM have no food safety problems with three market reactions (optimistic, normal, and pessimistic)
$\theta_s^u(j)$	The sales amount when the external environment has no food safety problem, but the imported FRM has a food safety problem with three market reactions (optimistic, normal, and pessimistic)
$\theta_u^s(j)$	The sales amount when the external environment has food safety problems, but the imported FRM has no food safety problem with three market reactions (optimistic, normal, and pessimistic)
$\theta_u^u(j)$	The sales amount when the external environment and the imported FRM have food safety problems with three market reactions (optimistic, normal, and pessimistic)
θ^*	The optimal order quantity
$\pi_{su}^j(\theta^*)$	Net profits of the three market statuses (o, n, p) under the condition of the external environment having no food safety problem and the imported FRM having a food safety problem
$\pi_{ss}^j(\theta^*)$	Net profits of the three market statuses (o, n, p) under the condition of both the external environment and the imported FRM having no food safety problems
$\pi_{us}^j(\theta^*)$	Net profits of the three market statuses (o, n, p) under the condition of the external environment having a food safety problem and the imported FRM having no food safety problems
$\pi_{uu}^j(\theta^*)$	Net profits of the three market statuses (o, n, p) under the condition of both the external environment and the imported FRM having food safety problems
$\pi_s(\theta^*)$	The expected revenue of the external environment having no food safety problems
$\pi_u(\theta^*)$	The expected revenue of the external environment having a food safety problem
$\pi(\theta^*)$	The maximum expected net profits

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